de Forest on the Audion

IN this paper delivered at an IRE meeting in 1913, one of the most colorful and controversial pioneers in radio and electronics discussed his most famous invention, the grid triode amplifier. It was one of the seminal inventions of the 20th century and gave rise to a major new industry. Although de Forest had patented the device in 1908, its potential usefulness as a telephone amplifier and radio amplifier was not generally recognized until 1912. It was converted into a reliable device by Arnold, Langmuir, and others in time to play a significant role in communications during World War I. See Robert A. Chipman, "De Forest and the Triode Detector," *Scientific American*, pp. 93–100, March 1965. Also see the papers by Susskind, Norberg, and Clark in the special issue of the PROCEEDINGS OF THE IEEE for September 1976. See also the discussion of the long controversy between de Forest and Armstrong in the PROCEEDINGS OF THE IEEE, p. 1082, August 1963.

Lee de Forest (1873–1961) was born in Council Bluffs, Iowa and graduated from Yale in 1896. He received a Ph.D. degree from Yale in 1899, and after working a few months for the Western Electric Company, he resigned to develop a radio system. The de Forest Wireless Telegraph Company was organized in 1902. His experiments with the Fleming diode that began in 1905 culminated in his invention of the triode that he patented in 1908. de Forest later sold the patent rights to A.T.&T. after a demonstration of the amplifier by de Forest and John Stone in October 1912. See the *DSB*, vol. 4, pp. 6–7 and the *NCAB*, vol. A, pp. 18–19.

THE AUDION—DETECTOR AND AMPLIFIER *

By Dr. Lee De Forest

Past-President, Society of Wireless Telegraph Engineers

Notwithstanding the now wide-spread use of the Audion as a detector in radio telegraph and telephone service few accounts of independent research into the nature of this instrument, or even cursory descriptions of its operation, seem to have been recorded, since the original paper presented before the American Institute of Electrical Engineers in 1906.

At that time, pending patent applications prevented the presentation of a detailed description of certain forms and improvements which are to-day common knowledge among radio engineers. It is my purpose herein to outline briefly the subsequent development of the Audion, both as a radio detector and as an amplifier of minute electric impulses.

For the benefit of those not familiar with radio detectors a brief description of the Audion follows:

A small incandescent lamp bulb is provided with a tantalum filament F (Figure 1), operated at from 4 to 15 volts. There is mounted close to one side of this filament, and parallel to its plane, a small plate of nickel, W. This plate is connected thru a telephone receiver, or other indicating device, R, with the positive terminal of a number of dry cells, B, arranged to give from 15 to 40 volts by the use of a multi-point switch. The negative terminal of this battery is connected to one side or terminal of the filament, which latter is lighted from a suitable storage battery, A.

Between the filament and the plate is mounted a third electrode, G, usually in the form of a grid-shaped wire, or a perforated plate. Approximately 1/16th of an inch (1.5 mm.) separates the grid from the plate on one side, and from the filament on the other.

In Figure 4, a regular commercial Audion receiver set, with its bulbs and adjusting switches, is shown. The two bulbs are mounted in an inverted position in order that the heated filaments do not sag into contact with the grid and their supporting wires after prolonged use. The plates of these bulbs are clearly visible.

* Delivered before The Institute of Radio Engineers, December 3, 1913.

Reprinted from *Proc. IRE*, vol. II, pp. 15–17, 19–21 (extract of a longer paper), 1914.

Figure 1

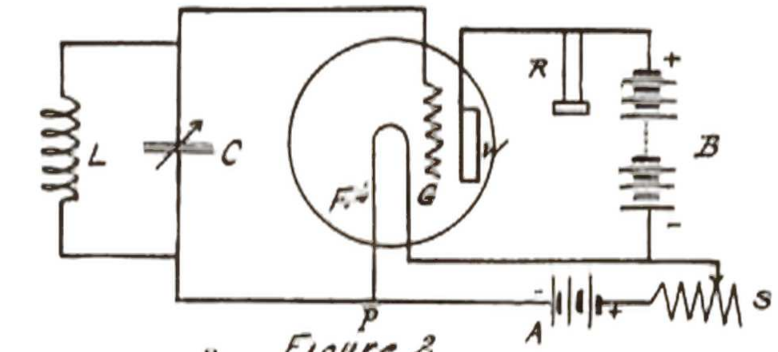


Figure 2

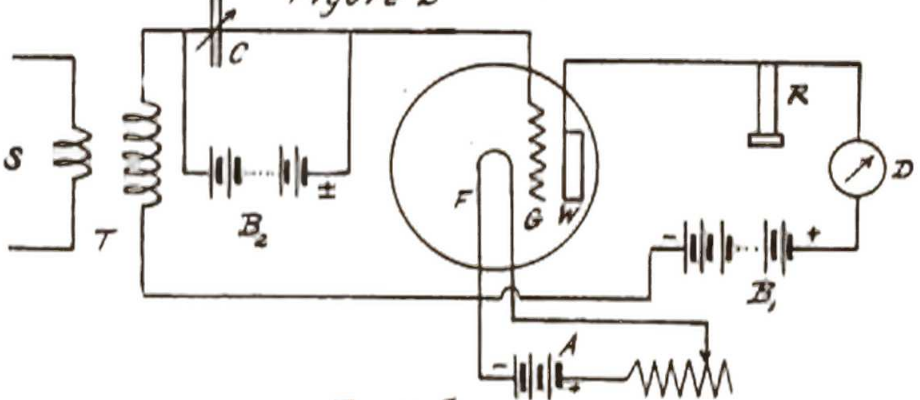
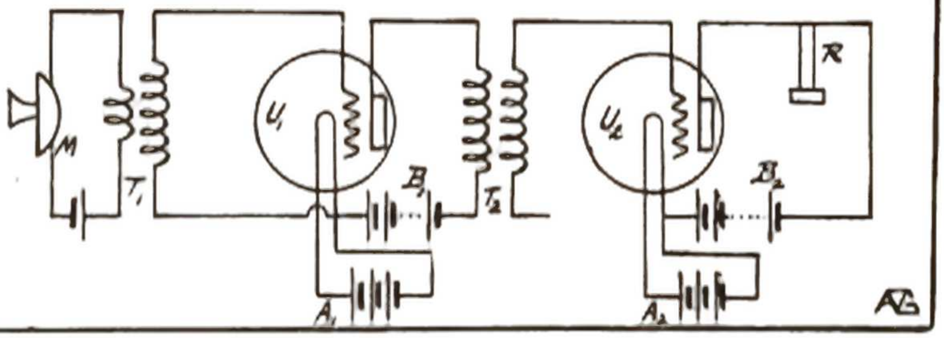


Figure 3



From the protected lower ends of these bulbs the terminal wires of the grid and plate pass out. The top three-point switch places either of the Audions in circuit. The center rotary switch inserts more or less resistance in the "A" battery circuit. The lower nine-point switch enables the insertion of extra batteries in the "B" battery circuit; these batteries being inserted in sets of three at a time.

When used as a detector, this grid electrode is connected to one terminal of the source of received radio frequency oscillations, the other terminal being connected to the Audion filament at P.

In the unlighted bulb, the resistance between the electrodes is practically infinite. When the filament is at white heat, a resistance of from 10,000 to 30,000 ohms is found between it and the cold anode. The value of this resistance depends upon a variety of conditions; such as filament temperature; size, shape, condition and location of the two outside electrodes; amount of electromotive force impressed on the gas; degree of vacuum; nature and degree of purity of the gas; magnetic forces to which the ions are subjected; *and the instantaneous value and sign of the electric potential impressed, or residing, on the intermediate, or grid, electrode.*

The introduction within the exhausted bulb of this third electrode (preferably, but not necessarily, located between the filament and the anode plate) at once placed the Audion in a distinct class, both as to sensitiveness when used as a responsive radio detector, and also as to its mode of operation. No longer, by any form of argument, could the grid Audion be classed as a rectifier, or "vacuum valve." Attempts to confuse it with the so-called Fleming "valve tube" have, I believe, failed to convince any one who has actually compared these two detectors, when each is properly constructed and connected. The difference observed in their operation is more than merely one of degree.

The vacuum valve, as first discovered by Edison, and carefully studied by Elster and Geitel*, has most marked rectifying properties, excelling in efficiency any electrolytic or crystal rectifier.

In this original device the cold electrode (or electrodes), was connected to the positive terminal of the filament. It was itself subjected to what may be, under favorable conditions, a very energetic bombardment of negatively charged corpuscles from the negative portions of the filament, while itself giving off prac-

* Wiedemann's Annalen, XVI, 1882.

tically no negative carriers. This valve rectifies small currents of any frequency, and can therefore be used in connection with a continuous current galvanometer to detect and measure the half-oscillations impressed on a tuned radio frequency transformer, the secondary terminals of which are connected to the anode plate and to one end of the filament respectively.

Starting from my experiments with the rectifying qualities of a gas flame (where the sources of heat energy and of the impressed e. m. f. across the electrodes were distinct and separate), the writer early found that if this incandescent-filament vacuum-rectifier were provided with a second battery, of proper voltage, independent of the lighting source and connected between one leg of the filament and the plate, (which plate must *always* be made the anode); then the device became more than a simple rectifier.

It took on the nature of a true detector, a "wave-responsive" device. In other words, it became to a degree a "trigger" tube, a genuine *relay*, giving responses in the indicating instrument (which was now preferably the telephone receiver) of considerably greater intensity than could be had from the received currents simply rectified. The regular and steady departure of negative ions, or carriers, from the cathode under stress of the "B" battery was found subject to sudden and great variations, following the variations of the applied radio-frequency e. m. f.; the degree of sensitiveness depending, for any given bulb, upon the heat of the filament and the amount of this applied "B" battery voltage.

At once the old vacuum valve took rank in sensitiveness with the electrolytic detector, until that time the most sensitive known.

The next step in advance was, as above stated, the introduction of the electrical impulses into the gaseous medium by means of a third and independent electrode.

This grid and filament, connected across the condenser of a receiving circuit, adds a slight capacity and a very high resistance shunt to that condenser. The additional damping thus introduced in the oscillating circuit is excessively small, its resonant qualities are unimpaired. The Audion thus lends itself, far more than any other form of energy-transforming detector, to sharp tuning. I have found properly designed receiving circuits equally sharply tuned, whether the Audion or the make-and-break contact detector (Poulsen tikker) be used therewith.

There appears to be no lower limit of sensitiveness to the Audion, no minimum of suddenly applied e. m. f., below which

the received impulses fail to produce any response. The exciting impulse, it is true, may be be too minute to cause a directly discernible effect in the "B" circuit, but if this effect be amplified through one or more steps, as will be hereafter described, the effect of the original excitation is found to exist.

Even in this day of universally accepted long-distance "wireless records," it is difficult for those who have not actually used the Audion detector to believe some of the receiving feats which are scored to its credit.

The Audion has the further advantage of entire absence of adjustment in the receiver itself. If the two battery potentials are once properly adjusted it requires no further attention. There is no fatigue under any conditions of use. A powerful spark discharge in close proximity may cause the "blue arc," or visible cathode discharge, to pass, but after a second or two this "paralysis" will automatically disappear, while a high resistance path (of the order of several megohms) between plate and grid will generally prevent this blue arcing.

This is therefore a suitable detector to use with a telegrapher's "breaking key." If a key-actuated relay be arranged to open the filament circuit with each depression of the Morse key, the Audion is always ready to catch the distant operator's call, or attempt to "break" in the midst of a message. On the other hand, the sensitiveness of the electrolytic and that of the best of the crystal detectors is frequently destroyed by one violent impulse, unless protected by shunting and disconnecting switches.

If there is any justification in the attempt to classify radio detectors as "current-operated" or "potential-operated" devices, there can be not the slightest hesitancy in classing the Audion as a potential-operated detector. Obviously it is in no sense a contact device, perfect or imperfect. Its response is strictly quantitative, up to the critical point of the voltage-response curve where "saturation" of ions or gas carriers begins. Up to that critical point the change in current passing from plate to filament is essentially proportional to the voltage applied to the grid electrode.

This voltage may be merely that of the hand discharging into the grid. When the lead to this grid is suddenly grasped, a click may be heard in the telephone receiver in the "B" circuit. If the charge thus impressed upon the grid be negative a repulsion or scattering of the negatively charged carriers emanating from the filament occurs. If the impressed charge be positive, then

these carriers may be attracted to the grid and discharged there, or delayed in the neighborhood. In either case, therefore, a diminution in the number of ions reaching the plate results, and we observe a diminution in the deflection of a sensitive milliameter or galvanometer in the "B" circuit when a prolonged series of impulses is delivered to the grid. The normal current is usually of the order of a milliampere, and its response diminution may vary from an undiscernible amount to 50 or even 90 per cent. of its full value.

An insight into what forces are at work in the Audion is afforded by experiments with a special circuit, such as that shown in Figure 2. When a negative charge is applied to the grid a click is heard in the telephones. When a positive charge is applied, almost no sound is heard. If G is negatively charged to 20 volts, while a sound from telephonic currents from source S is being received, the sensitiveness of the Audion is practically annulled. When G is positively charged the sound is greatly reduced, but not to the foregoing extent. This experiment seems to show that in the normal operation of the Audion the imposition of a charge, negative or positive, upon the grid acts either to repel from its neighborhood the ionic carriers or to hold them idle there, thus in either case increasing the effective resistance in the filament-to-plate path.

The first establishment of the ionic circuit of an Audion when the filament is suddenly lighted is perfectly silent—no sound is heard in the telephone, altho a galvanometer in series shows that the "make" is practically instantaneous. The establishment of the gaseous conductivity is sufficiently gradual, however, to make no sound. I do not know of any similar rapid circuit-closing device which is thus silent. While this "B" current assumes nearly its maximum amplitude practically instantly, its full value may not be reached for several seconds. A slow and irregular creeping of the milliameter needle reveals how gradually the ions adjust themselves to a completely stable condition. Upon the rupture of the filament circuit, however, the "B" circuit opens practically instantly, invariably accompanied by a click in the receiver telephone.

Referring again to the arrangement in Figure 2: when the grid is positively charged, the voltage of B_2 made nearly equal to that of B_1, and the heating current carefully adjusted, a very intense whistling note may be obtained in the telephone receiver, loud enough to be heard a meter from the instrument.

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